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Treatment of Aqueous Waste Streams from KRW Energy Systems Coal Gasification Technology

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16. ABSTRACT The paper gives results of a bench-scale evaluation to determine the extent to which process wastewaters from the KRW Energy Systems coal gasification process are treatable using commercially proven wastewater treatment technology. (NOTE: The process--formerly called the Westinghouse gasification process--is representative of ash agglomerating fluidized-bed coal gasification technology which has developed to the point where commercial-scale systems are now being planned and which has been the subject of extensive environmental, health, and safety evaluations.) The program was conducted in cooperation with KRW which provided wastewater samples, process information, and technical review. The treatment processes considered in this evaluation were suspended solids removal, steam stripping, cyanide conversion, and biological oxidation. A design basis for each treatment was developed from the bench-scale data and incorporated into a conceptual plant wastewater treatment system design. The treatability data presented show that gasification process wastewaters can be effectively treated using conventional treatment technologies.

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SUMMARY

Ash agglomerating fluidized-bed coal gasification technology has developed to the point where commercial-scale systems are now being planned. The KRW Energy Systems (KRW) coal gasification process (formerly called the Westinghouse gasification process) is representative of this technology and has been the subject of extensive environmental, health, and safety evaluations. The Department of Energy (Morgantown Energy Technology Center), the Gas Research Institute, and the Environmental Protection Agency (Industrial Environmental Research Laboratory, Research Triangle Park, North Carolina) have sponsored a bench-scale evaluation to determine the extent to which process wastewaters from the KRW gasification process are treatable using commercially proven wastewater treatment technology. The program was conducted in cooperation with KRW which provided wastewater samples, process information, and technical review. The treatment processes considered in this evaluation were suspended solids removal, steam stripping, cyanide conversion, and biological oxidation. A design basis for each treatment process was developed from the bench-scale data and incorporated into a conceptual plant wastewater treatment system design. The treatability data presented illustrate that gasification process wastewaters can be effectively treated using conventional treatment technologies.

INTRODUCTION

Coal gasification technology for the production of gaseous and liquid fuels and synthesis gas is being used or considered for several facilities in the United States. Treatment of wastewater from

these facilities is an important consideration from both an environmental and a cost perspective because most coal gasification processes produce relatively large volumes of gas condensates. These condensates typically contain a variety of dissolved gaseous contaminants, suspended solids, and dissolved organic and inorganic compounds. At present the application of conventional industrial wastewater treatment processes to wastewaters produced by different types of coal gasification processes is not well defined. Thus, there is a need for data defining a basis of design for conventional treatment technologies in the treatment of specific gasification wastewaters.

In 1982 the Department of Energy's Morgantown Energy Technology Center (METC), the Gas Research Institute (GRI), and the Environmental Protection Agency (EPA/IERL-RTP) recognized the need for a program to provide process design data for ash agglomerating fluidized-bed gasification process wastewater treatment. In response to this need, METC developed preliminary conceptual designs and a program plan to obtain process design and performance data for treating wastewaters from a commercial-scale KRW-based synfuels plant. As a result of this plan, METC, GRI, and EPA entered into a joint program to develop performance data, design parameters, and environmental characterization data during a series of bench-scale treatability tests which used wastewaters from a fluidized-bed coal gasification process development unit. These data were then used to develop conceptual treatment system designs from which the cost of wastewater treatment was estimated. This study is the first phase of a program that may eventually include pilot- and commercial-scale testing of selected wastewater treatment processes.

This paper presents a brief summary of the approach used to develop a conceptual treatment system design for process wastewaters from a commercial-scale KRW coal gasification plant. The conceptual design approach is presented in a stepwise fashion to highlight the wastewater characteristics, treatability data, and rationale behind design decisions.

BASE CASE PLANT

The first step in development of a conceptual wastewater treatment system design is to define the flow and composition of the wastewater streams requiring treatment and the extent of treatment required. Before this can be done the plant site must be selected, and a preliminary process design for the facility must be completed. All plant systems that will produce or collect wastewater requiring treatment must be identified. This includes wastewater streams from gasification and gas conditioning processes (e.g., gas quench or cooling, acid gas removal, synthesis processes), pollution control systems (e.g., sulfur recovery), and auxiliary systems (e.g., steam generators, coal storage, and handling) required to support the gasifier operation. Since coal gasifiers can be designed to produce fuel gas or synthesis gas for hydrocarbon liquids or substitute natural gas (SNG) production, the number of wastewater streams is dependent upon the end product produced at a specific facility. For the purposes of this paper the base case plant is assumed to be configured to produce medium-Btu gas suitable for use as industrial fuel gas. A flow diagram showing major process elements for such a gasification facility is presented in Figure 1. The difference between this design and that of an SNG plant is the absence of a methanation step for converting the gas from medium-Btu gas to SNG.

Figure 1 also indicates some of the waste streams that may be produced from such a facility. The streams important to a process wastewater treatment system design include quench liquor, gas

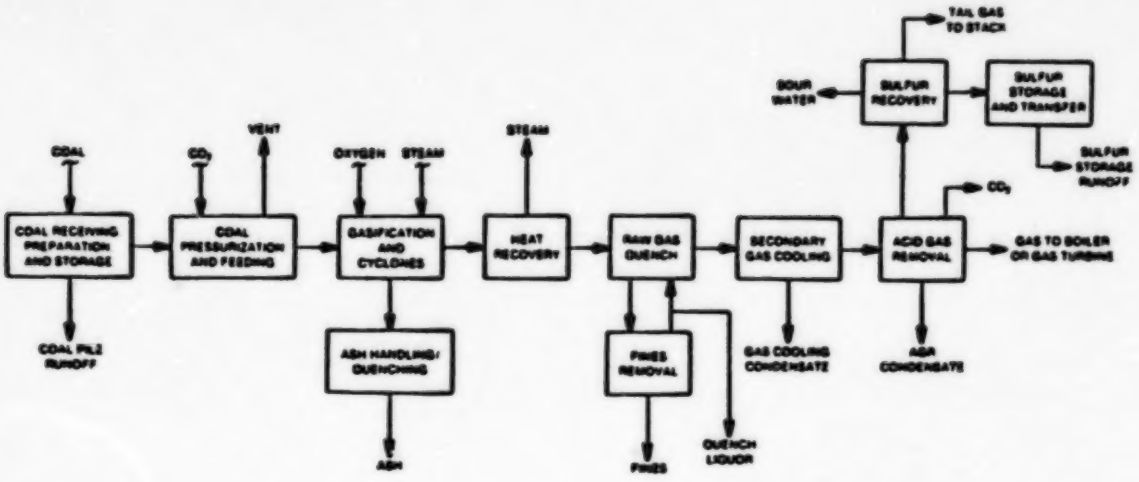

Figure 1. Typical Westinghouse-Based Gasification Facility Process Flow Diagram

cooling condensate, process area drains, and sour water from the sulfur recovery system. A few acid gas removal (AGR) systems operate at relatively low temperatures and, as a result, produce a condensate stream. This AGR condensate stream is not common to all AGR systems; therefore, it is not considered in the conceptual design that follows.

Table 1 presents the flow rates and approximate compositions of the key wastewater streams listed above. In the normal configuration for the gas cooling and quench system, the quench liquor and gas cooling condensate are combined prior to leaving the system. This combined stream has the largest flow rate and also contains high concentrations of several pollutants. The quench liquor/condensate stream is characterized by relatively high concentrations of inorganic nitrogen compounds (e.g., ammonia, cyanide, and thiocyanate) and sulfides and low concentrations of organics. The sour water and process area drains contain a few of these pollutants in relatively low concentrations. The removal of inorganic nitrogen compounds and sulfides is the major concern in treatment of the wastewaters from a KRW-based gasification facility.

The stream flow rates and characteristics were selected from those developed in the Keystone Feasibility Study by Westinghouse Electric Corporation, Synthetic Fuels Division, for the U.S. Department of Energy (1). This study involved a facility consuming 2120 Mg/day of dried Pittsburgh No. 8 coal to produce approximately 1.43E+05 actual m^3/day of medium-Btu gas. This proposed facility is very similar to the typical plant configuration shown in Figure 1.

TREATMENT PROCESS SELECTION

The selection of a treatment approach for a specific wastewater requires consideration of effluent discharge limitations, site-specific constraints such as water quality and availability, as well as the potential for pretreatment and discharge to a publicly owned treatment works. Treatment goals to meet site-specific requirements are the basis for selection of treatment processes. For this study it is assumed that all treatment will be done at the gasification facility and the treated effluent will be discharged to a fast flowing stream. Thus a predicted effluent limitation for the facility must be established.

Defining acceptable effluent limitations for specific parameters in a coal gasification plant discharge stream is difficult since few synfuels facilities have obtained discharge permits. Effluent quality goals developed by the Department of Energy for synfuels facility discharges are listed in Table 2 (2). The ranges for specific parameters are used in this paper for comparison with the predicted effluent quality of the treated wastewater from the conceptual wastewater treatment system. These effluent quality goals are presented for comparison purposes only and should not be construed to be entirely representative of the effluent limitations that must be met at any specific site. A facility operator may be required to comply with either more or less stringent effluent limitations than those shown.

During the KRW gasification wastewater treatment system design program, five wastewater treatment processes were evaluated in bench-scale tests. Approximately 7600L of quench liquor/condensate wastewater was treated on a continuous or semicontinuous basis to determine the performance, design parameters, and limitations of the use of these treatment processes on this wastewater. In addition the environmental characteristics of all key influent, effluent, and

TABLE 1. WASTEWATER STREAM COMPOSITION AND FLOW RATE[a]

Parameter	Quench Liquor/ Process Condensate Blowdown[b]	Sour Water (sulfur recovery)[b]	Process Area Drains[b]
Flow Rate, Lpm(gpm)	916(242)	76(20)	473(125)
pH, units	7.5	9.5	7.0
Total Dissolved Solids	2,000	--	5
Total Suspended Solids	10	--	25
COD	300[c]	60[b]	45
TOC	100	--	10
Ammonia	1,000	--	--
Sulfide	500	30	--
Total Alkalinity as $CaCO_3$	2,200	300	--
Chloride	500	--	--
Cyanide (total or free)[d]	60(total)	--	--
Sulfate	60	--	--
Thiocyanate	120	--	--
Benzene	0.4	--	--
Naphthalene	1	--	--
Phenol	0.2	--	--

[a]All units in mg/L unless otherwise indicated. Dashes indicate that the constituent is not expected to be in significant concentration or present in the water stream.
[b]Reference 1.
[c]Calculated from constituents.
[d]Includes both free and complexed cyanide.

TABLE 2. EXAMPLE EFFLUENT QUALITY RANGES FOR SYNFUELS FACILITIES[a]

Parameter	DOE Estimate for Synfuels Facilities[b]
GENERAL	
Total Dissolved Solids	500-5000
Color	Absent[c]
Odor	Absent[c]
Total Suspended Solids	[d]
ORGANIC INDICATORS	
Biochemical Oxygen Demand	10-30
Chemical Oxygen Demand	30-300
Oil & Grease	1-10
Total Phenols	0.05-0.2
NITROGEN/SULFUR SPECIES	
Ammonia	1-10
Nitrates & Nitrites (as N)	[d]
Total Cyanide	0.02-0.2
Sulfide	0.03-0.3
TRACE ELEMENTS	
Arsenic	10^{-6}-10^{-3}
Boron	0.5-5
Cadmium	0.001-0.1
Chromium (total)	[d]
Mercury	0.0005-0.005
Lead	0.005-0.5
Selenium	0.001-0.1
Zinc	[d]
TOXIC ORGANIC COMPOUNDS	
Individual PAH[e]	10^{-6}-10^{-3}

[a]Reference 2.
[b]Concentrations in mg/L.
[c]A low concentration but undefined at this time.
[d]No estimates of quality ranges were developed.
[e]Estimate for individual polycyclic aromatic hydrocarbons (PAH) that may be present in a given wastewater stream.

secondary waste streams for each wastewater treatment process were determined within the limitations of the bench-scale systems.

The four treatment processes evaluated were solids removal, steam stripping, activated sludge operating in a nitrification mode, and cyanide conversion. An additional bench-scale test was performed to evaluate the potential for reuse of treated wastewaters in a process cooling tower. The tests performed in each process evaluation are listed below.

- Solids removal focused on the coagulation and settling of fine particulate matter that will not settle out of solution by gravity within a reasonable time period. This type of treatment would be required to protect steam stripping equipment from fouling with solids.

- Steam stripping was evaluated in a column having a variable packing height at four different steam-to-wastewater ratios. These tests were run at the as received pH of 7.6. One additional test run was conducted after adjusting the inlet wastewater pH to 9.0.

- The stripper effluent was treated in an activated sludge process operating with nitrifying bacteria. This investigation focused on the feasibility of simultaneously removing ammonia, thiocyanate, and residual organic carbon from the wastewater.

- Two reactions for the conversion of free cyanide were evaluated in the laboratory:

  -- The first reaction evaluated was between free cyanide and sodium polysulfide to form thiocyanate as the end product. Both the rate and extent of conversion to thiocyanate were investigated.

  -- The second reaction involved the formation of a ferrocyanide complex which results from the reaction of free cyanide and ferrous sulfate. The stoichiometry of the ferrocyanide complex formation reaction was determined.

  The products of both reactions, thiocyanate and the ferrocyanide complex, can be removed from the wastewater by further treatment by biological oxidation and ion exchange, respectively.

Strict quality assurance and quality control protocol was maintained during the process evaluation tests. This protocol included review of sampling, analysis, and record keeping procedures by Radian's QA/QC coordinator; calibration of analytical instrumentation; use of well documented analytical procedures; check of all calculations; and analysis of blanks, spiked samples, and replicates.

The results of the bench-scale evaluations of steam stripping, cyanide conversion, and activated sludge treatment process are summarized in Table 3 for the primary contaminants in the KRW gasification process quench liquor/gas cooling condensate stream. Solids would be removed in the quench/cooling system at an actual facility and is not included here for this reason. Steam stripping with no pH adjustment is effective in removing gaseous pollutants to

TABLE 3. SUMMARY OF RESULTS FOR BENCH-SCALE TREATABILITY TESTS FOR KRW GASIFICATION WASTEWATERS

Wastewater Treatment Process	Primary Contaminant(s)	Influent Contaminant Concentration (mg/L)	Effluent Contaminant Concentration (mg/L)	Average Contaminant Removal (percent)
Stream Stripping (no pH adjustment)[a]	Ammonia	790-810	193-280[b]	72
	Sulfide	1-58	1-18[b]	57
	Cyanide (total)	13-63	1.1-1.8[b]	95
Cyanide Conversion to Thiocyanate[c]	Cyanide (free)	150	<8	95
Activated Sludge (nitrification mode)	Ammonia	190	<5	>99
	Cyanide	1.4	<1	>30
	TOC	58	<3	>95
	COD	210	<21	>90
	Thiocyanate	150	<1	>99
	Sulfide	18	<0.1	>99

[a]Treatability tests conducted using KRW gasification process quench liquor/gas cooling condensate.
[b]Ranges reflect tests at steam ratios ranging from 120 to 479 kg steam/m^3 and packing heights ranging from 0.6 to 1.2 m.
[c]The economic application of this process is limited to low volume, high temperature waste streams with relatively high cyanide concentrations.

relatively low levels. However, the effluents from this process still contain significant concentrations of key pollutants and would require further treatment to meet effluent quality goals. Optimization of the steam stripping process by pH adjustment of wastewater would still not produce an effluent ammonia concentration comparable to the effluent quality listed in Table 2.

The activated sludge process operating in a nitrification mode was shown to consistently reduce all contaminants except complexed cyanide in the stripper effluent to concentrations that will meet the effluent quality ranges. Cyanide conversion to thiocyanate was found to be effective for high temperature streams with high cyanide concentrations. The use of this process would appear to be limited to streams (such as stripper overhead condensates) meeting those criteria.

These three treatment processes could provide the nucleus of a process wastewater treatment system for KRW gasification wastewaters. The processes have been demonstrated on the bench-scale with the quench liquor/gas cooling condensate wastewater. The inclusion of other process wastewater streams and the sequence of treatment is the final step in conceptual design.

CONCEPTUAL DESIGN

The selected treatment processes must be organized into a treatment sequence such that effluent quality ranges in Table 2 are achieved and the overall cost of wastewater treatment is minimized. Figure 2 presents a schematic of a treatment system developed to achieve these objectives. In this scheme the quench liquor and process condensate streams are treated by steam stripping separately from the other wastewater streams. The overhead condensate from the stripper is treated in a cyanide conversion reactor to form biodegradable thiocyanate. This treated condensate stream (which contains high concentrations of ammonia, sulfide, thiocyanate, and possibly organics) is recombined with the stripper effluent, sour water from sulfur recovery, and process area drains in the equalization basin. The basin allows adequate time for the chemistry of the wastewaters to equalize and provides surge capacity to minimize flow rate and chemistry variations which may upset the downstream biological treatment process. The bioreactor is an activated sludge system operated in a nitrification mode. The effluent from the clarifier portion of the activated sludge system is polished with a filter before entering a holding pond. In this pond the effluent may be mixed with other treated wastewaters such as cooling tower blowdown, stormwater runoff, and other utility plant wastewaters. This pond would have adequate capacity to hold several days of wastewater production to ensure that effluent quality is maintained through start-up and upset conditions. This pond should also be equipped with the capability to recycle wastewater to appropriate treatment units when contaminant levels are above the desired target effluent quality.

The untreated and treated wastewater compositions and flow rates for the process streams shown in Figure 2 are summarized in Table 4. The stream numbers in the table correspond with those in the diamonds in Figure 2. The quench liquor/gas cooling condensate (Stream 1), sour water from sulfur recovery (Stream 4), and process area drains (Stream 5) were presented and discussed earlier in the paper. The treated effluent compositions and contaminant removals shown are based on the bench-scale results in Table 3 which were developed during the KRW gasification wastewater bench-scale treatability study.

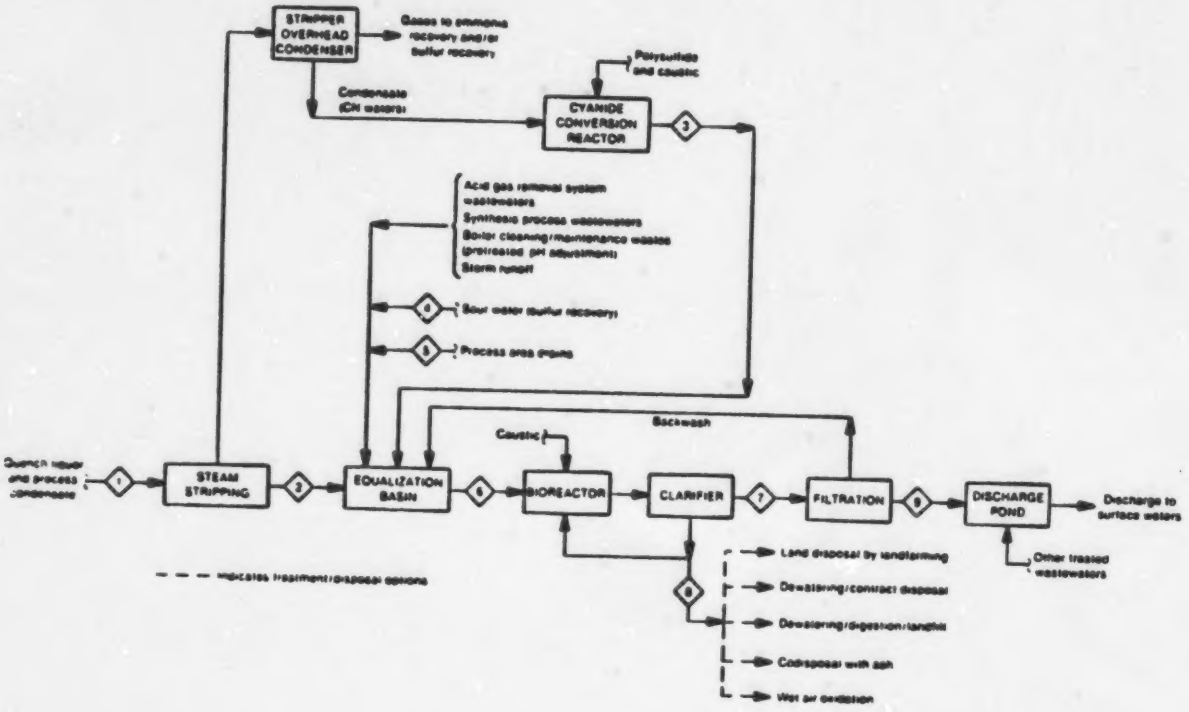

Figure 2. Conceptual Design of Treated Effluent Discharge Scheme

TABLE 4. STREAM COMPOSITIONS AND FLOW RATES FROM CONCEPTUAL WASTEWATER TREATMENT SYSTEM[a]

	Quench Liquor/ Process Condensate Blowdown[b]	Stripper Effluent	Cyanide Conversion Effluent (Overhead Condensate)	Sour Water (Sulfur Recovery)[b]
Stream No.:	1	2	3	4
Flow Rate, Lpm(gpm):	916(242)	931(246)	204(54)	76(20)
Chemical Constituent				
pH, units	7.5	6.8	9.0	9.5[e]
Total Dissolved Solids	2,000	2,000	25	
Total Suspended Solids	10	10	0	
COD	1,300[c]	300[c]	3,900[c,d]	60[c]
TOC	100	75	170	
Ammonia	1,000	250	1,000[c]	
Sulfide	500	15	1,600	30
Total Alkalinity as $CaCO_3$	2,200	100	3,700	300
Chloride	500	490	0	
Cyanide (total or free)[f]	60 (total)	2 (total)	13 (free)	
Sulfate	60	59	0	
Thiocyanate	120	120	550[c]	
Nitrate as N	<0.5	<0.5	<0.5	
Benzene	0.4	0	2	
Naphthalene	1	0	4.3	
Phenol	0.2	0	0.09	

(continued)

TABLE 4. STREAM COMPOSITIONS AND FLOW RATES FROM CONCEPTUAL WASTEWATER TREATMENT SYSTEM (Continued)[a]

Chemical Constituent	Process Area Drains[b]	Equalization Basin Effluent[g]	Bioreactor Clarifier Effluent	Bioreactor Clarifier Waste Sludge	Treated Effluent to Discharge Pond
Stream No.:	5	6	7	8	9
Flow Rate, Lpm(gpm):	473(125)	1680(445)	1680(444)	4(1)	1680(444)
pH, units	7.0	7.0	7.0	7.0	7.0
Total Dissolved Solids	5	1,100	4,000[e]	4,000[e]	4,000[e]
Total Suspended Solids	25	13	43	12,000	5
COD	45	250	20	20	20
TOC	10	65	<5	<5	<5
Ammonia		260	<5	<5	<5
Sulfide		<1[h]	<0.1	<0.1	<0.1
Total Alkalinity as $CaCO_3$		520	30	30	30
Chloride		270	270	270	270
Cyanide (total or free)[f]		3(total)	1(total)	85(total)	1(total)
Sulfate		650	860	860	860
Thiocyanate		130[d]	<1	<1	<1
Nitrate as N		<0.5	290	290	290
Benzene		0.3	0	0[i]	0
Naphthalene		0.6	0	0[i]	0
Phenol		0.01	0	0[i]	0

[a]All units in mg/L unless otherwise indicated. Blanks indicate that concentration of the constituent is not expected to be significant.
[b]Reference 1.
[c]Concentrations calculated from stream constituents; ammonia concentration in Stream 3 is estimated.
[d]Increase due to conversion of free cyanide to thiocyanate.
[e]Increase due to addition of sodium hydroxide to maintain pH.
[f]Total cyanide includes both complexed and free forms.
[g]Composite of Streams 2, 3, 4, and 5.
[h]Aeration required to reduce sulfide prior to biological oxidation.
[i]May contain traces of these organics adsorbed on the biomass.

The stripper effluent reflects the resulting composition of the quench liquor/gas cooling condensate stream after steam stripping. The effluent would contain a maximum of 250 mg/L of ammonia, 15 mg/L of sulfide, and 2 mg/L of total cyanide with no adjustment of the wastewater pH. The residual cyanide was found to be in a stable (complexed) form in the bench-scale studies. The aromatic compounds were found to be stripped and concentrated in the stripper overhead condensate. Other organics which are primarily organic acids remain in the stripped wastewater. The stripper effluent flow rate increases by 2 percent due to condensation of steam in the stripper column.

The stripper overhead water vapor is assumed to be condensed and treated for cyanide conversion using sodium polysulfide as the reagent. The thiocyanate produced by this reaction is biodegradable; therefore, this stream can be combined with other streams in the equalization basin for treatment by the activated sludge process. The flow rate shown for this stream is based on condensation of all water vapor in the stripper overhead stream. In an actual system only a portion of the vapor in the stripper overhead gases may be condensed. The chemistry of the resulting wastewater stream will vary considerably depending on the pH of the scrubbing solution and gas liquid contact time. The process would be optimized to remove cyanide and organics, and thus all of these compounds in the overhead vapor would enter this condensate stream. Of this cyanide, 95 percent is assumed to be converted to thiocyanate, resulting in a thiocyanate concentration of 550 mg/L. The ammonia concentration in this stream has been estimated to be comparable to the stripper feed stream. Other parameters have been calculated based on the major chemical components and laboratory data.

The blended composition of stripper effluent (Stream 2), cyanide conversion effluent (Stream 3), sour water (Stream 4), and process area drains (Stream 5) is shown as the equalization basin effluent (Stream 6) in Table 4. This combined stream contains significant concentrations of ammonia and sulfide and low concentrations of total cyanide and TOC. The sulfide concentration in this combined wastewater stream may have an inhibitory effect on the activated sludge process. Oxidation of the sulfide by aeration in the equalization basin is required to eliminate these inhibitory effects. Adequate treatment to lower the free cyanide concentration to less than 1 mg/L is also essential to avoid inhibitory effects on the activated sludge (nitrification) process. Because of the characteristic chemistry of the wastewater and the operational pH of the bioreactor, free cyanide above 1 mg/L would likely strip to the atmosphere during biological treatment. Therefore, a low level of free cyanide in the influent to the bioreactor is also a requirement of the design in order to prevent adverse environmental impact. Other components are present in concentrations comparable to or less than those found in the quench liquor or gas cooling condensate.

The bioreactor is operated as an activated sludge system with autotrophic (nitrifying and sulfur oxidizing) bacteria. The bioreactor effluent will contain low concentrations of ammonia, sulfide, and cyanide, as well as COD and TOC. The total dissolved solids concentration of the wastewater is increased significantly due to the addition of sodium hydroxide to maintain the pH in the reactor near neutral. The addition of sodium hydroxide is required to neutralize acids produced as a by-product of ammonia oxidation by the bacteria. A significant increase in the concentration of sulfate

occurs in the wastewater. This sulfate is produced as a by-product of the thiocyanate oxidation reaction. The available carbonate alkalinity in the wastewater is used as a carbon source by the autotrophic (nitrifying) bacteria, resulting in a low concentration of this constituent in the effluent. The TOC in the wastewater is oxidized by the heterotrophic bacteria also present in the bioreactor. All aromatic compounds (benzene, naphthalene, and phenol) are oxidized or adsorbed on the biomass in the bioreactor.

Comparison of the effluent quality in Table 2 with the treated wastewater composition (Stream 9) indicates that the effluent quality targets have been met for all species except total cyanide. Bench-scale testing indicated that the residual cyanide is present as a complex. Blending with other treated wastewater streams in a holding pond prior to discharge from a facility would reduce the residual cyanide concentrations further. Toxicity testing of the combined discharge stream may be required to demonstrate to regulatory agencies that the impacts of this low level of complexed cyanide are negligible.

In the treatment of KRW gasification wastewaters only two major secondary waste streams are generated. These streams, shown in Figure 2, are stripper overheads and waste sludge from the bioreactor clarifier. The treatment of the stripper overhead condensate has been previously discussed. The uncondensed gases in the overheads will be routed to either sulfur recovery or combustion.

The bioreactor clarifier produces a relatively low volume of waste sludge as shown in Stream 8. This low volume is characteristic of systems with predominantly autotrophic bacteria which grow at low rates compared to heterotrophic bacteria which consume organic carbon as their primary substrate. After dewatering, this stream may be reduced to less than 3.8 Lpm of sludge requiring disposal.

The bioreactor waste sludge disposal will depend on the composition of the sludge and many site-specific factors. Analysis of waste sludge during bench-scale tests indicated an accumulation of complexed cyanide in the sludge which would be a major concern in sludge disposal. The sludge may also contain other trace elements and possibly certain toxic organics adsorbed on the biomass during treatment. Determination of these sludge characteristics and leaching tests are the first step in defining a disposal method. Several options are available for disposal of this sludge including:

- Land disposal by landfarming;
- Dewatering and contract disposal;
- Dewatering and landfilling;
- Digestion of solids, dewatering, and landfilling of residuals;
- Codisposal with gasifier or other ash; and
- Wet air oxidation or incineration.

Where site conditions or regulations do not allow landfilling of large volumes of solids, wet air oxidation or incineration may be used to oxidize these solids and virtually eliminate this stream.

These processes may still leave a small amount of ash which may contain trace elements removed in the bioreactor. However, these options allow the designer considerable flexibility in treatment and disposal of this stream.

CONCLUSION

The test program and the conceptual design presented indicate that the treatment technologies evaluated can be effectively applied in a process wastewater treatment system to produce water that may be dischargeable. The sequence of treatment and the applicability of one process over another depends on the flow rate and characteristics of each stream, and as a result, will vary from plant to plant. The program has provided designers with a basis for making judgments with respect to process selection, treatment sequence, and process performance for the treatment of fluidized-bed gasification wastewaters which has heretofore not been available.

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